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Optimization of dam operation rule to improve water environment in Monobe River

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ABSTRACT**:** In the basin of Monobe river, one of the major rivers in Kochi prefecture in Japan, environmental conditions are being worsened. In those environmental problems, draught water flow is especially a fundamental issue because it often decouples and decreases habitat of water creatures.
Draught water flow is caused by water right and dam operation rule with emphasis on hydraulic power generation and flood control. In our study, the authors focused on dam operation. Purpose of this study is to quantify tradeoff relationship between hydraulic power generation and protection of river environment. The authors simulated dam operation to evaluate hydraulic power impact for power generation and river environment by changing dam operation rule.

KEYWORDS: draught water flow, river environment, hydraulic power generation, dam operation

1. BACKGROUND AND OBJECTIVE OF RESR|EARCH

The Length of Monobe River is 71km, and the basin area of Monobe River is 468km^2. There are three dams, six hydraulic plants, two intake weirs for irrigation. Those infrastructure facilities were made in 1950's. The river development gives the society social benefits in terms of power generation, water use and flood control.

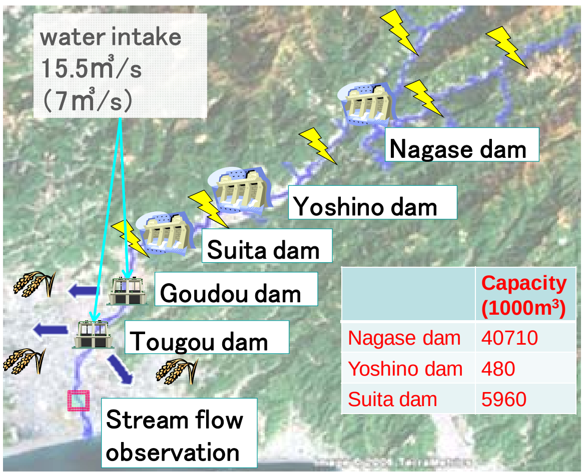
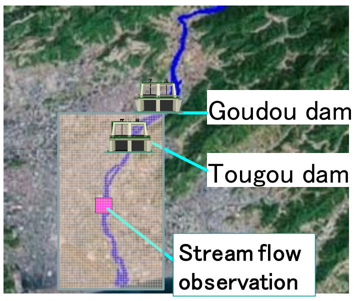


Figure 1 Monobe river basin

However, the development has large negative impacts on river environment, which are muddy water, draught water flow, and shore erosion. The authors focus on the draught water flow because this decouple and decrease habitat of water creatures.

Throughout the month of October to November in 2007, mean daily flows in most days are below 1 m^3 per second. As a result, most of sweet fish cannot move to spawning grounds.



Minimum flow rate to maintain the river environment in downstream of Tougou dam

1/1～10/15	1.9m³/s
10/16～12/31	2.9m³/s

Figure 2 Minimum flow rate to maintain the river environment

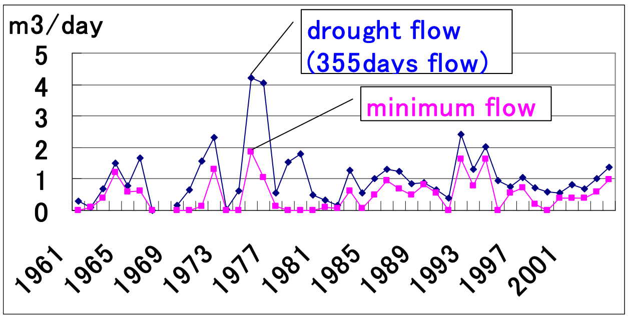


Figure 3 stream regime in Monobe River

As demonstrated in Figure 2 and Figure 3, 355days flow and the minimum flow were below the minimum water flow rate to maintain the river environment in most years. Furthermore, the minimum flow of some years records 0 m^3 per second. Causes of draught flow are irrigation right and dam operation. The authors focus on dam operation in this study.

The authors will explain documented dam operation rule. To reduce probability of drought water flow, documented dam operation rule is obligated to maintain certain water level. However, actual dam operation doesn't conform to the rule because maintaining a certain reservoir water level increase gate discharge. Discharge from dam is divided into gate discharge and water consumption for hydraulic power generation; therefore, increasing gate discharge means decreasing water consumption for hydraulic power generation. In addition, maintaining certain reservoir water level may increase difficulty for flood control. However, the following dam operation may causes depletion of reservoir storage.

The authors should evaluate risk of drought under conditions of new irrigation right. Irrigation right is updated in this year. Farmer's demand for early crop of rice makes irrigation period about two weeks earlier than the conventional irrigation right. However, it may bring negative impacts for river environment, because the starting period of the new irrigation period coincides with the period for sweet fish to run upstream and low rainfall term.

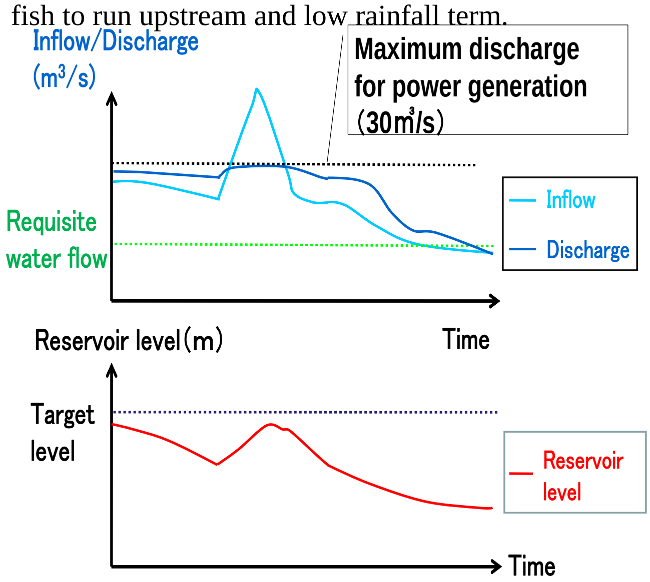


Figure 4　Actual dam operation

1.1 Objectives of this study

Purposes of this study are to quantify tradeoff relationship between hydraulic power generation and river environment and to evaluate risk of drought under conditions of the updated irrigation right.

2. METHODOLOGY

Figure 5 shows an outline of this study. First, the authors simulated the two output variables, the hydraulic power generation and stream regime, that is, drought days, when dam is operated according to the documented operation rule. Next, an attempt is made to evaluate changes of these two output variables when dam is operated differently.

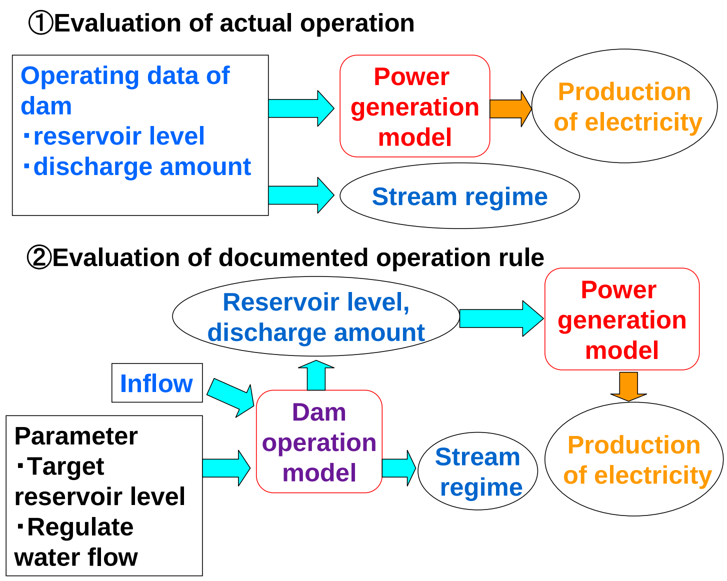


Figure 5 Outline of this study

2.1 Dam operation model

The pricipal author developed a dam operation model based on realistic dam operation rules by Visual Basic for Application. This model repeats conditional branching. If the reservoir level is higher than the target water level, the dam discharges the sum of inflows to the dam and the regulate flow..The regulate water flow is a parameter to lower the reservoir level. If heavy rain appears, dam eases discharge by amount of space of dam until the reservoir level rises the above limit water level. As a result, water flow in downstream is decreased. When inflow to dam is insufficient for requisite water flow in downstream, dam supply water flow by expending storaged water. As previously mentioned, the model has two parameters, the regulate water flow and the target reservoir level.

The model is run for only Nagase dam in the upstream. The model does not consider flow control functions of Yoshino and Suita dams in the midstream because flow control functions of those dams are very small in contrast to Nagase dam.

If discharge of Suita dam is less than the requisite water flow amount, which is the sum of irrigation right of the minimum flow to maintain river environment, that day is counted as a day of drought water flow in the model.

2.2 Hydraulic power generation evaluation model

In general, production of electricity is estimated by formula. Output of power generation equals generating efficiency “μ g” times discharge amount for power generation “Q” times drop ”H”. In reality, generating efficiency is a function of discharge for power generation and drop. In short, the formula is very complicated.

$$P = 9.8 \times Q \times H \times \mu g$$

Formula 1 Output of power generation equal

In this study, the relationship between output of power generation, discharge flow for power generation and reservoir level is approximated with a regression model using basic data for hydraulic power generation planning

Figure 6 shows accuracy of the hydraulic power generation evaluation model. Error is within +2.3% to -2.5%. First, this error may be caused by error of data. In flow, discharge and reservoir level data is daily value averaging short term changes. Thus, using such a dayly averaged data may become a cause of error. Second, ignoring flow control functions of Suita and Yoshino dams may cause error of hydraulic power generation evaluation model.

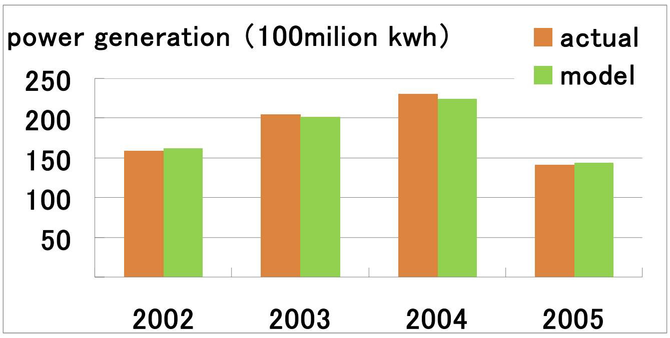


Figure 6 Total power generation production

2.3 Statistical estimation process of output from models

The authors estimated drought days in downstream and power generation each day for 12 years from 1994 to 2005. Next, we estimated sum of those each year. Next, we calculated average values and standard deviation of those. Finally, we obtained “best” parameters to try to simultaneously optimize power generation production and days of drought by the use of goal programming.

3 Result of analysis under old irrigation right

We first solved the above-mentioned optimization problem under the old irrigation right and analyzed tradeoff relationship between power generation and water environment.

3.1 Power generation production

Figure 7 shows average values of and standard deviations of power generation. The authors first prepared 100 sets of parameters and evaluated power generation for each parameter. However, some sets of parameters increased difficulty for flood control. Thus, sets of parameters creating the situation in which dam water level exceeds 191 meters of the target reservoir level are removed from the analysis.

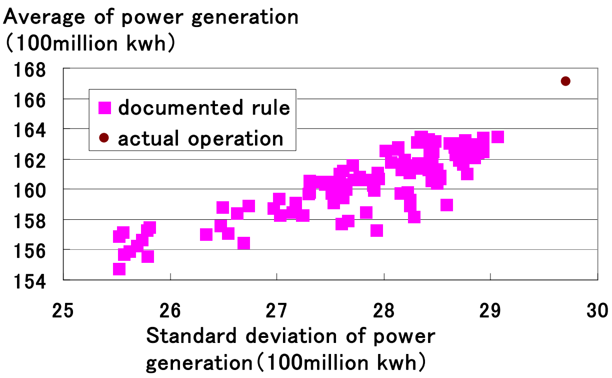


Figure 7 power generation under old irrigation right

3.2 Days of drought

Figure 8 shows drought days under the old irrigation right. Average of drought days decreased. Standard deviation of drought days increased in contrast to actual dam operation.

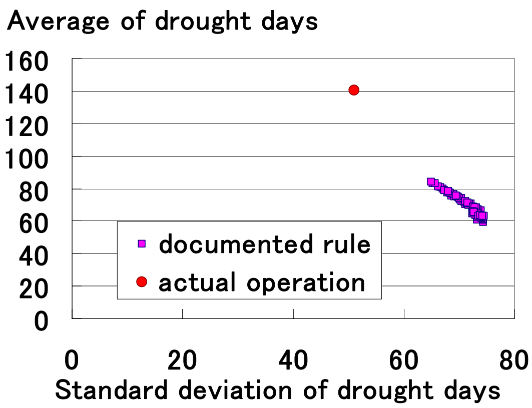


Figure 8 Drought days under old irrigation right

3.3 Relationship between power generation and water environment in downstream

Figure 9 shows the average and standard deviation of the optimized solution by goal programming and actual value. X axis means days of drought, and Y axis means power generation production. Under old irrigation right, the average and standard deviation of power generation decreased by 2.7% and by 4.5%, respectively. In short, considering the magnitude of standard deviation of power generation, when the dam is operated subject to the optimum rule, possibilities of lowering the power generation below its actual value is small statistically. Thus, the optimum dam operation would improve water environment dramatically without sacrificing power generation.

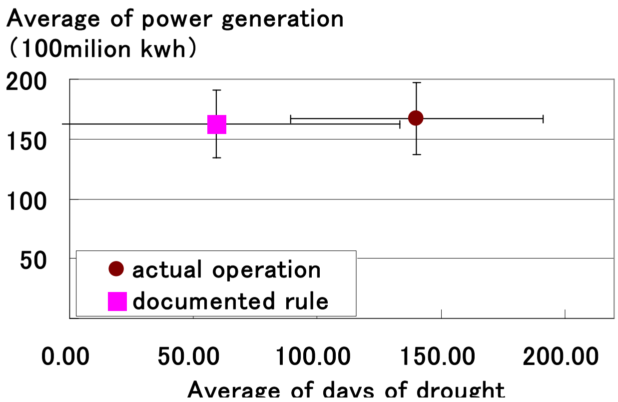


Figure 9 Relationship between power generation and stream regime under old irrigation right

4 Result of analysis in condition of new irrigation

In analysis under the new irrigation right, the authors first evaluated risk of drought in spring, estimated power generation production and days of drought. In addition, we optimized those values and analyzed tradeoff relationship between power generation and water environment.

4.1 Risk of drought in spring

As a result of simulation under the new irrigation right, days of drought decreased generally, however, results of simulation indicates increasing risk of drought in spring. Figure 10 shows cumulative water budget of Nagase dam in 2001 spring. Under the new irrigation right, water budget of Nagase dam falls into the red on March 21 when the irrigation period is started. 23,500,000m^3 of reservoir storage, which is 70% of max reservoir storage, is depleted until early May. As a result, reservoir storage is reduced to almost zero on April 29.

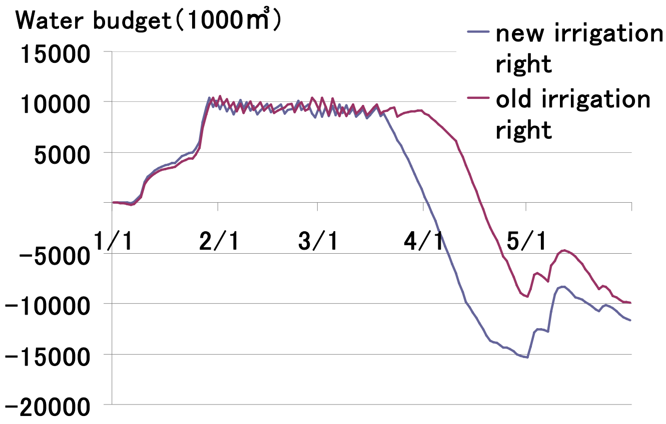


Figure 10 cumulative water budget of Nagase dam in 2001 spring

As demonstrated in Figure11, monthly precipitation is less than the average in 2001 spring. As can be seen, it is probable that amount of rainfall less than or equal to rainfall in 2001 spring gives large negative impact to agriculture and river environment..

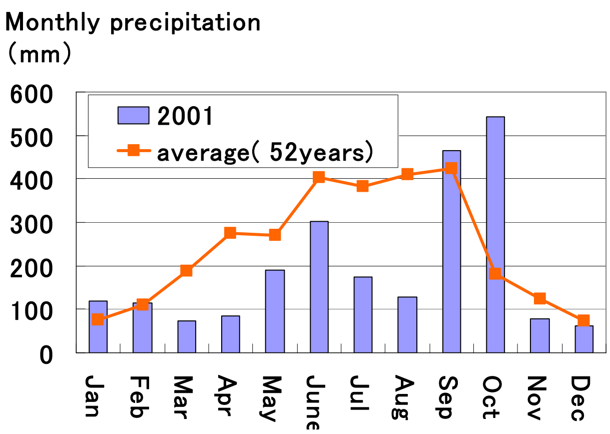


Figure 11 monthly precipitations in 2001

We calculated non-exceedance probability of monthly precipitation which is equal to precipitation in 2001 spring based on an assumption that precipitation distribution can be approximated by lognormal distribution. Non-exceedance probability of monthly precipitation, which is equal to precipitation of April in 2001, is 1.1%. However, we considered this calculation of non-exceedance probability is underestimated.

Figure 12 shows monthly precipitation of April from 1954 to 2006. As demonstrated in the figure, it is possible that long term trend of monthly precipitation of April shows decreasing trend. In addition, monthly precipitation which is equal to 2001 had appeared in 1989.

Therefore, we thought rainfall as small as that in 2001 could occur at higher than the estimated probability of 1.1%.

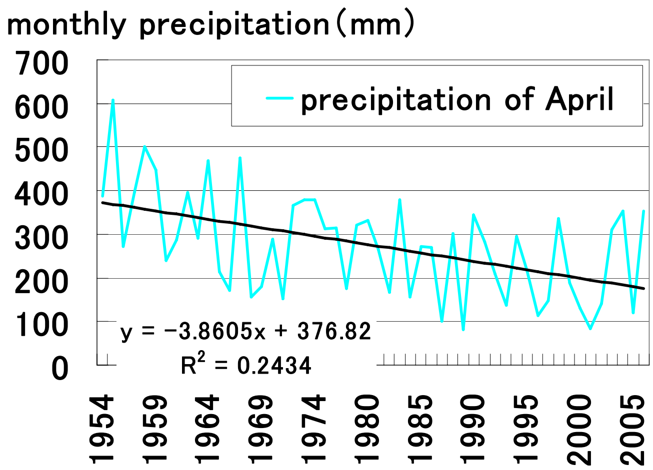


Figure 12 precipitation of April in upstream of Monobe river

4.2 Power generation

Figure12 shows power generation associated with proposed sets of parameters under the new irrigation right and the old irrigation right. The power generation associated with the current operation rule is also included.

Power generation under the new irrigation right is similar equal to power generation production under old irrigation right.

We evaluated power generation associated with parameters except those creating the situation the dam water level exceeds the above-mentioned 191 meters of the target reservoir level in the same way of analysis as the old irrigation right.

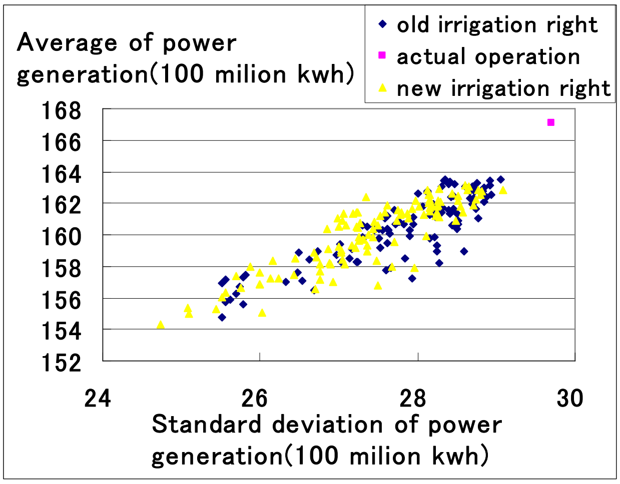


Figure 13 Power generation production

4.3 Days of drought

Figure 14 shows drought days under the new irrigation right. Except for 2001, entire drought days decreased dramatically.

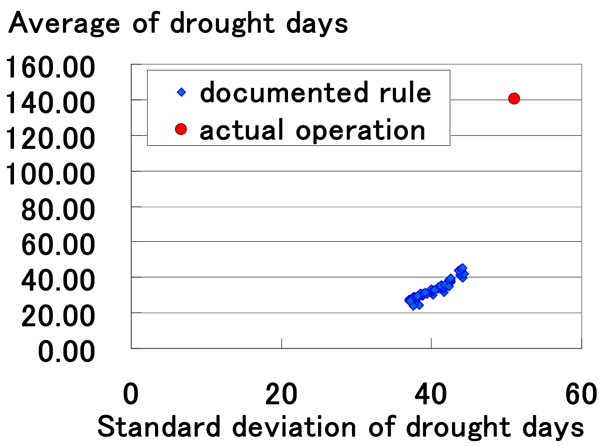


Figure 14 Drought days in new irrigation right

4.4 Tradeoff Relationship between power generation and water environment in downstream

Under the new irrigation right, average of power generation production decreased by 2.7%, and its standard deviation decreased by 3.7%. Average of drought days decreased by 83%, and its standard deviation decreased by 26%. Except for 2001, water environment may be improved.

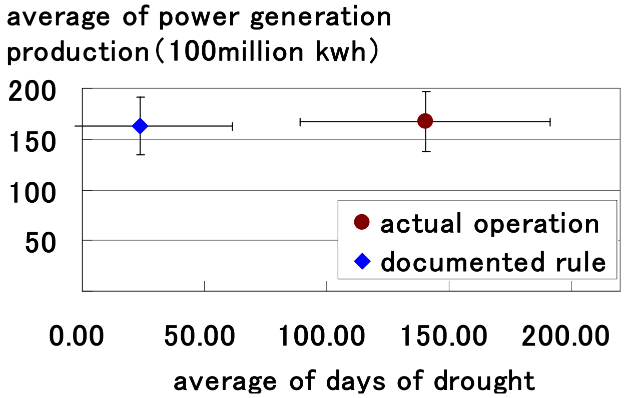


Figure 15 Relation between power generation and stream regime in new irrigation right

5. Conclusion

In this study, the authors quantified tradeoff relationship between water environment and hydraulic power generation. The results shows a possibility of reducing occurrence of drought water flow without sacrificing much of hydraulic power generation. Under the new irrigation right, however, risk of making the dam water budget deficit exists. Future assignments of our study are to evaluate changes of social benefit by loss of hydraulic power generation, evaluate risk of drought under the new irrigation right in more detail, and evaluate risk of flood control by changes of dam operation.

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